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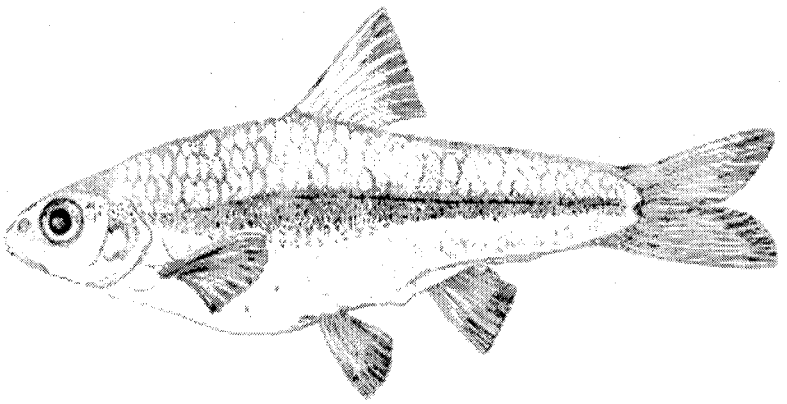

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Historical and Recent Fish Fauna of the Lower Pecos River

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Abstract

The lower Pecos River extends 770 km, crossing the Permian Basin and Edwards Plateau from 17 km northwest of Carlsbad, New Mexico to the Rio Grande, near Langtry, Texas. Recent (1991 to 1999) fish collections were depauperate compared with historical collections from the area. Recent composition of the ichthyofauna was divisible into three assemblages, associated with the following river segments: between Brantley and Red Bluff dams, Red Bluff Dam to Live Oak Creek confluence, and Live Oak Creek to the Rio Grande, but this segregation was not evident within historical collections. Historically, 27 native fish species occurred in all three segments, whereas in recent collections only nine native fishes occurred in all three. Recent native fish species richness was reduced between 47 and 54% (by segment) from historical collections. Riverine species were poorly represented in recent collections. Seven native and one nonnative fishes historically represented the genus *Notropis*, but only three species of the genus were found in recent collections. Incidental stockings and bait bucket releases established nonnative euryhaline fishes (*Fundulus grandis*, *Menidia beryllina*) that represented significant proportions of recent collections. A similar introduction resulted in replacement of *Cyprinodon pecosensis* by a hybrid swarm (*C. pecosensis* x *C. variegatus*). Nonnative game fishes represented a minor portion of recent collections, despite concerted efforts to establish several species. Diminishing springflows, nonnative fish introduction and spread, and toxic algal blooms further threaten native fish populations, while habitat and water quality deterioration favor nonnative species to the detriment of natives. Appreciation of lower Pecos River historical significance to native Rio Grande fishes is important for promoting conservation of remnant native species assemblages both within the lower Pecos River and throughout the Rio Grande basin.

Introduction

The degraded condition of the lower Pecos River in recent decades was evidenced by elevated salinity (Davis, 1987), toxic algal blooms (James and De la Cruz, 1989; Hubbs, 1990; Rhodes and Hubbs, 1992), and replacement of a native pupfish by a hybrid swarm with a nonnative congener (Echelle and Connor, 1989). Nineteenth century accounts of the lower Pecos River (Pope, 1854; Dearen, 1996) are very different from more recent accounts (Grozier et al., 1966; Davis, 1980), suggesting that the historical fish fauna may have also been different from the present fauna. This paper summarizes historical fish records, compares them with recent (1991 to 1999) records, and provides a historical perspective on habitat and faunal conditions recently observed.

Study Area

The Pecos River is the largest Rio Grande tributary in the United States. The mainstem extends 1,490 km, from more than 3,960 m above sea level in the Sangre de Cristo Mountains, New Mexico, to roughly 305 m above sea level at the river mouth on the Texas-Coahuila border (Figure 1). In the Pecos River drainage, cold- and cool-water streams are present in montane headwaters of the mainstem and tributaries. The middle and lower Pecos basins (Figure 1) include warm-water habitats such as the Pecos River

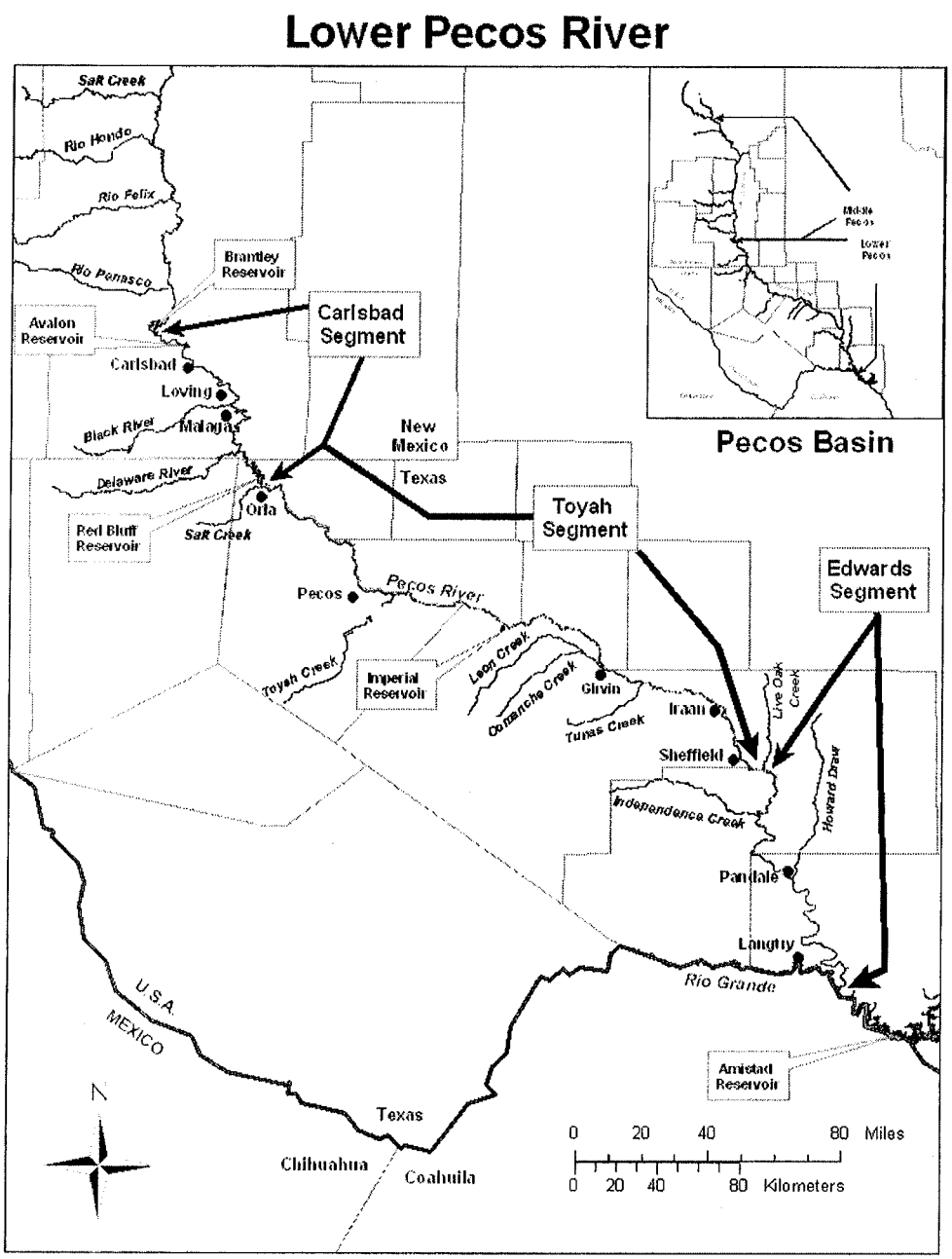

Figure 1. Map of Lower Pecos River, New Mexico and Texas, with the three fish faunal segments delineated. Also included are selected reservoirs, tributaries, and cities.

mainstem, spring-fed tributaries, and spring-fed/floodplain wetlands. This paper is solely concerned with the lower Pecos River mainstem.

The lower Pecos River extends roughly 770 km, crossing the Permian Basin for about 575 km (Hill, 1996) and then the Edwards Plateau for 195 km (King, 1935). The Pecos River, Permian Basin section begins 17 km northwest of Carlsbad, New Mexico (Kelley, 1971; Bachman, 1980), where the river traverses Barrera del Guadalupe, extending downstream to the Edwards Plateau, near Iraan, Texas (Anaya, 2001). Within this stretch, the Pecos River crosses a series of alluvial basins (Maley and Huffington, 1953; Jones, 2001). Downstream, the Pecos River is incised within the Edwards Plateau and confined by limestone cliffs (Thomas, 1972).

The lower Pecos River receives surface inflow from the middle Pecos River (Figure 1) and from local tributaries that originate in mountains to the west (Guadalupe, Delaware, Apache, Davis, Barrilla, Del Norte, and Glass mountains) (Hill, 1996). However, even the largest western tributaries (e.g., Dark Canyon, Black River, Delaware River, Salt Creek, Toyah Creek, Coyanosa Draw, Tunis Creek) sustain only intermittent surface flow. Headwater flows normally sink into the ground at the base of the mountains, but rise to the surface downstream where water-bearing strata outcrop or encounter impermeable strata (Brune, 1981). A number of significant aquifers, present throughout the lower Pecos River basin, interact hydrologically (discharge or recharge) with surface waters (Richey et al., 1985; Hill, 1996; Mace et al., 2001). An exceptional example is the regional flow system that extends west of the surface drainage boundary and apparently distributes groundwater to multiple Pecos River tributaries by interconnection of the following aquifer basins: Ryan Flat, Lobo Flat, Salt Basin, Apache Mountains, Balmorhea Basin, and Toyah Basin (Sharp, 2001). The east edge of the lower Pecos River drainage is bounded by the Southern High Plains from which no major tributaries enter (Lee, 1925), because of high percolation rates into surficial sands (Jones, 2001). Within the Edwards Plateau, spring-fed tributaries (e.g., Live Oak Creek, Independence Creek, Howard Creek) join the river from both east and west (Brune, 1981). The lower Pecos River terminates at the Rio Grande, near Langtry, Texas (Figure 1).

The lower Pecos River forms the boundary between the Kansan, Balconian, and Chihuahuan biotic provinces, while the Navahonian province delineates the northwestern boundary and the Tamaulipan province extends up the Rio Grande to near the Pecos River confluence (Blair, 1950). Fishes representative of all five provinces occupy the lower Pecos River, accounting for a relatively diverse native fish fauna (Hubbs, 1957; Smith and Miller, 1986). Most of the lower Pecos River Basin lies within the Chihuahuan province where many native species are threatened or endangered (Edwards et al., 1989).

HISTORY

According to historical accounts, the lower Pecos River was deep and swift, with steep, unstable banks, a shifting sand substrate, and abundant quicksand (Pope, 1854; U.S. Geological Survey, 1900; Brune, 1981; Leftwich, 1987; Dearen, 1996). In 1854, Pope reported, "The Pecos traverses its valley in a very tortuous course, and with a current of about two and a half miles to the hour, and from five to twenty feet depth of water." Rapids or falls were present wherever the Pecos River encountered bedrock or where tributaries discharged gravel and boulders (Pope, 1854; Hufstetler and Johnson, 1993; Dearen, 1996). Pecos River water was often turbid and had relatively high mineral content, giving the river a reputation for having only bad water. Some springs in the area were very salty or sulphurous (Pope, 1854; Brune, 1981) and saline wetlands were common within the floodplain (Schroeder and Matson, 1965; Leftwich, 1987), but Pope (1854) noted "Although the water of the Pecos is somewhat salty. . . the use of it has not been followed by any injurious consequences to the health, of a serious character."

Anglo-American settlement along the lower Pecos River began in the 1860s and intensified with the coming of railroad and irrigation companies (Lingle and Linford, 1961). Large-scale water development began at the head of the lower Pecos River with Avalon (1891) and McMillan (1893) dams (U.S. Geological Survey, 1900; Freeman and Bolster, 1911; Grover et al., 1922; Meinzer et al., 1926; U.S. National Resources Planning Board, 1942). Immediately thereafter, numerous river diversions were established between Carlsbad, New Mexico, and Girvin, Texas (Taylor, 1902; Grover et al., 1922; U.S. National Resources Planning Board, 1942). Sediment deprivation resulting from McMillan and Avalon dams changed Pecos River substrate from sand to bedrock (in swift areas) and silt (in slow areas). With capture and diversion of surface flows, groundwater springs became the primary source of flow in the mainstem lower Pecos River (Taylor, 1902; Grover et al., 1922; Robinson and Lang, 1938). For example, in May 1918, the Pecos River gained 47.8 cubic feet per second (cfs) (1.35 cms) between the New Mexico/Texas border and

Girvin, Texas (Grover et al., 1922). In 1925, W.T. Lee observed "[the Pecos River] is a stream of considerable size at all times. . . Records of two gauging stations near Carlsbad, 2.5 miles apart, show that 80 second-feet of water enters the river in this distance." Once the lower Pecos River was fragmented, each river segment developed water quality and flow characteristics specific to local conditions (i.e., the continuity of the mainstem river environment was disrupted) (U.S. National Resources Planning Board, 1942).

Additional mainstem reservoirs were established during a second development period, beginning in the 1930s (Lingle and Linford, 1961). Red Bluff Dam (1936), near the New Mexico/ Texas border, supplied seven irrigation districts in Texas and Sumner Dam (1937) of the middle Pecos River supplied Carlsbad Irrigation District. Both facilities captured floodwaters and sediments. Even with new storage facilities, expanding development and drought caused irrigators to increasingly rely on groundwater, particularly after 1942 (Thomas et al., 1963; West and Broadhurst, 1975). As a result, groundwater flow within adjoining aquifers was altered (Thomas et al., 1963; Mace et al., 2001). Particularly heavy groundwater pumping in the Permian Basin altered groundwater flow-paths, virtually eliminating historical base-flow gains in most areas and causing significant base flow losses in some (Grozier et al., 1966; West and Broadhurst, 1975; Hiss, 1980; Brune, 1981).

Davis (1987) summarized a dramatic, human-induced increase in total dissolved solids (i.e., salinity) between 1938 and 1981. Flood control (Howard, 1942; Davis, 1980, 1987), stratification in impoundments and riverine pools (Davis, 1980, 1987), saline aquifer intrusion (Hood, 1963; Havenor, 1968; Jones, 2001), irrigation return flows (Robinson and Lang, 1938; U.S. National Resources Planning Board, 1942; LaFave, 1987; Ashworth, 1990; Mace et al., 2001), oil field pollution (Wiebe et al., 1934; Campbell, 1959; Grozier et al., 1966; Ashworth, 1990), and *Tamarix* (Davis, 1987), each contributed to salinity increase. Because each of these factors was initiated prior to 1935, when the first water quality investigations were conducted (Robinson and Lang, 1938; U.S. National Resources Planning Board, 1942), pre-development salinity is unknown, but was presumably lower than first recorded in 1935.

For purposes of this paper, the lower Pecos River was divided into three segments (Figure 1): 1) Carlsbad segment: McMillan Dam (replaced by Brantley Dam in 1988) to Red Bluff Dam; 2) Toyah segment: Red Bluff Dam to Live Oak Creek confluence; and 3) Edwards segment: Live Oak Creek confluence to the Rio Grande. Segments were distinguishable from each other with respect to flow regime, geomorphology, and water chemistry (Hillis, unpublished; Davis, 1980, 1987; Sublette et al., 1990; Rhodes and Hubbs, 1992).

HISTORICAL FISH SURVEYS

Ichthyological surveys and summaries seldom have considered the lower Pecos River as a unit. Miller (1977) provided the only species list for fishes specific to the area. Important summaries included Evermann and Kendall (1894), who listed fishes taken from the Pecos River basin during railroad and boundary surveys, and Smith and Miller (1986), who listed fishes native to the entire Pecos River basin and discussed their zoogeographic origins. This paper primarily follows Smith and Miller (1986) in designation of fish species as native (but see Table 1).

Historical lower Pecos River fish surveys were not equal among segments. The Carlsbad segment was most heavily surveyed and included the earliest lower Pecos River collections (Pope [1854] at Delaware River confluence [Evermann and Kendall, 1894]). Extensive New Mexico Department of Game and Fish (NMDGF) surveys between 1955 and 1970 captured fish using a fish barrier trap and gill-nets below McMillan Dam (Navarre, 1959, 1960; Little, 1961b, 1963a, 1963b). Gill-nets were also used on the mainstem river between Tansill Dam in the city of Carlsbad and Red Bluff Reservoir (Little, 1964c, 1964d, 1965), and within Avalon Reservoir, Carlsbad Municipal Lake, and Red Bluff Reservoir (Little, 1960a, 1960b, 1961a, 1964b, 1964c). Fishes were also salvaged from irrigation canals (Little, 1964a). General fish community surveys, using seines, were conducted by Koster and associates, University of New Mexico (Koster,

Table 1. Native fishes known from the mainstem lower Pecos River. Inclusion of species as native follows Smith and Miller (1986) except where noted (numbered footnotes). Recent status of native fishes, based on 1991 to 1999 collections is given: Thriving = frequent and widespread collections in high number (thousands); Stable = reproductive populations in moderate numbers (hundreds); diminished = range reduced, occurrence in moderate numbers; Tenuous = few collections, low numbers (<25); ? = absent from collections but possible via dispersal from Rio Grande; ?? = undetermined due to difficulty in identification and/or lack of documentation; Absent = missing from recent collections, with the year of most recent collection from the lower Pecos River given for each species. The known historical and recent distribution of each species is given by segment. Lettered footnotes provide references of taxonomic interest. Names and taxonomic order follow Mayden et al. (1992).

Species	Recent Status	Historical Distribution	Recent Segment Distribution
Atractosteus spatula[1]	ABSENT - 1958	EDWARDS?	Unknown, possible in Edwards
Lepisosteus oculatus[2]	ABSENT - 1958	TOYAH - EDWARDS?	Unknown, possible in Edwards
Lepisosteus osseus	STABLE	ALL	All, abundant in Carlsbad
Anguilla rostrata	ABSENT - 1948	ALL	-
Dorosoma cepedianum	THRIVING	ALL	All, abundant in Carlsbad & Toyah
Campostoma anomalum[*]	ABSENT - 1958	EDWARDS	-
Cyprinella lutrensis	STABLE	ALL	All, abundant in Carlsbad
Cyprinella proserpina	STABLE	TOYAH - EDWARDS	Edwards, common
Dionda episcopa	DIMINISHED	ALL	Edwards, associated with springs
Hybognathus amarus	ABSENT - 1963	CARLSBAD - TOYAH	-
Macrhybopsis a. aestivalis[a]	TENUOUS	ALL	Toyah & Edwards, rare
Notropis amabilis[b3]	TENUOUS	ALL	Edwards, uncommon
Notropis braytoni	TENUOUS	ALL	Toyah & Edwards, rare
Notropis buchanani	ABSENT – 1965	EDWARDS	-
Notropis jemezanus	ABSENT - 1987	ALL	-
Notropis l. ludibundus[c]	TENUOUS	CARLSBAD - TOYAH	Toyah, rare
Notropis orca[4]	ABSENT - 1940	EDWARDS	-
Notropis simus pecosensis[d]	ABSENT - 1987	CARLSBAD	-
Phenacobius mirabilis[5]	??	?	-
Pimephales promelas	STABLE	ALL	Carlsbad, abundant
Pimephales vigilax	STABLE	TOYAH - EDWARDS	Edwards, common
Rhinichthys cataractae[*]	ABSENT - 1947	CARLSBAD	-
Carpiodes carpio elongatus[e]	DIMINISHED	ALL	Carlsbad, common
Cycleptus elongatus[f]	DIMINISHED	CARLSBAD, EDWARDS	Carlsbad, mostly between Brantley & Avalon dams, possible in Edwards
Ictiobus bubalus	TENUOUS	ALL	Carlsbad, rare, possible in Edwards
Ictiobus niger[6]	??	?	Unknown, confusing taxonomy
Scartomyzon congestus	DIMINISHED	ALL	Carlsbad & Edwards, common in Carlsbad
Astyanax mexicanus	DIMINISHED	ALL	Carlsbad & Edwards, uncommon
Ictalurus furcatus[g^]	ABSENT - 1958	ALL	Unknown, possible in Edwards
Ictalurus lupus	??	ALL	Unknown, difficult identification and taxonomy
Ictalurus punctatus[^]	DIMINISHED	ALL	All, most common in Carlsbad
Pylodictis olivaris[^]	TENUOUS	ALL	Carlsbad & Toyah, rare
Fundulus zebrinus	ABSENT - 1993	ALL	-
Lucania parva[h]	THRIVING	ALL	All, most abundant in Toyah
Cyprinodon pecosensis	ABSENT – 1994	ALL	-
Gambusia affinis[7]	THRIVING	ALL	All, abundant in Carlsbad & Toyah
Gambusia speciosa	STABLE	EDWARDS	Edwards
Lepomis cyanellus	DIMINISHED	ALL	All, common in Carlsbad
Lepomis gulosus	DIMINISHED	ALL	Carlsbad
Lepomis macrochirus[^]	STABLE	ALL	Carlsbad & Toyah, common in Carlsbad
Lepomis megalotis	DIMINISHED	ALL	All, rare in Toyah
Micropterus salmoides[^]	DIMINISHED	ALL	All, uncommon
Etheostoma grahami	TENUOUS	EDWARDS	Edwards, uncommon
Etheostoma lepidum	ABSENT – 1992	CARLSBAD	-

Table 1. (cont.)

Species	Recent Status	Historical Distribution	Recent Segment Distribution
Percina macrolepida	TENUOUS	CARLSBAD - TOYAH	Carlsbad, between Brantley & Avalon dams, Black River confluence
Aplodinotus grunniens	TENUOUS	TOYAH - EDWARDS	Toyah, rare, possible in Edwards
Cichlasoma cyanoguttatum	TENUOUS	TOYAH - EDWARDS	Toyah & Edwards, rare

[1]Not included by Smith and Miller (1986), but known from at least Amistad Reservoir (J.F. Scudday, Sul Ross State University, pers. comm.), possibly upstream to New Mexico (Hubbs, 1957).
[2]Not included by Smith and Miller (1986), but well known from the lower Pecos River throughout Texas (e.g., Campbell, 1959; Hillis, unpublished).
[3]Incorrectly listed as extinct by Smith and Miller (1986; Hubbs et al., 1991).
[4]Not included by Smith and Miller (1986), but known from a collection by R.M. Bailey at U.S. Highway 90 bridge (Chernoff et al., 1982).
[5]Listed as native by Smith and Miller (1986), but nonnative by Sublette et al. (1990). Very few historical records (see Campbell, 1959).
[6]Listed by Koster (1957) and also by Smith and Miller (1986). The author has found no reference to extant museum specimens or credible accounts.
[7]Not included by Smith and Miller (1986), but considered native to the Pecos River (Rauchenberger, 1989 and many others).
[a]Rio Grande speckled chub, following Eisenhour (1997).
[b]Pecos River variant (low mean scale radii counts), following Coburn (1982).
[c]Use of nominal subspecies name follows Tanyolac (1973) as modified by Mayden and Gilbert (1989).
[d]Pecos bluntnose shiner, following Chernoff et al. (1982).
[e]Slender carpsucker, following Hubbs and Black (1940).
[f]Rio Grande basin variant, following Burr and Mayden (1999) and Buth and Mayden (2001).
[g]Rio Grande basin variant (unique spotting and head shape), see Garrett and Edwards (2001).
[h]Pecos River race, following Hubbs and Miller (1965).
*Native to Pecos basin, but may be accidental or introduced in lower Pecos River.
^Native species that were also introduced as game-fish, likely from sources outside the lower Pecos River basin

1957; Museum of Southwestern Biology records) and, subsequently, by Sublette and associates, Eastern New Mexico University (Sublette, 1975; Hatch, 1985; Sublette et al., 1990). Comprehensive information on rare native fishes of New Mexico was provided by Hubbs and Echelle (1972), while Hatch (1985) and Sublette et al. (1990) summarized historical fish collections for that state.

Historical fish surveys were least extensive in the Toyah segment (Table 2). Collections, primarily by Bailey and others (University of Michigan Museum of Zoology records), Texas Parks and Wildlife Department (TPW; Campbell, 1959), and Hubbs and Springer, University of Texas at Austin (UT-Austin; Hubbs, 1954, 1957; Texas Natural History Collection records), provided data on fish distribution between 1940 and 1960. Later collections by Davis in 1976, Texas Department of Water Resources (Davis, 1981), Hillis in 1979, and Rhodes et al. in 1987-1988, both of UT-Austin (Hillis, unpublished; Hillis et al., 1980; Rhodes and Hubbs, 1992; Texas Natural History Collection records), and Linam and Kleinsasser, TPW in 1987 (Linam and Kleinsasser, 1996) provided more recent information, but only Linam and Kleinsasser surveyed upstream of Girvin, Texas. Historical Toyah segment fish surveys relied entirely on seines.

Historical fish surveys from the Edwards segment were less extensive than the Carlsbad segment, but greater than from the Toyah segment (Table 2). Except for a TPW survey (Campbell, 1959), surveys were primarily conducted by UT-Austin associates (Hubbs, 1954, 1957; Treviño-Robinson, 1955, 1959; Hillis et al., 1980; Rhodes and Hubbs, 1992; Texas Natural History Collection records) and Tulane University associates (Tulane University Museum of Natural History records) (Table 3). Historical Edwards segment fish surveys relied on seines except for three gill net collections reported by Campbell (1959).

MATERIALS AND METHODS

The historical (1939-1990) fish fauna of the lower Pecos River was summarized using published literature, agency reports, museum records (Museum of Southwestern Biology, University of Michigan Museum of Zoology, Texas Natural History Collection, Tulane University Museum of Natural History), and personal communications (G.P. Garrett, TPW; J.P. Karges, The Nature Conservancy; S.P. Platania, Museum of Southwestern Biology; J.F. Scudday, Sul Ross State University). Occurrence of fishes in historical collections was tabulated for each of the three lower Pecos River segments. Recent (1991-1999) records reported by Hoagstrom (1994), Larson (1996), and Garrett (1997), along with unpublished data from the NMDGF/U.S. Fish and Wildlife Service (FWS), and D.M. Hillis of UT-Austin, were compared to pre-1991 records.

This paper was primarily concerned with fish community surveys from the mainstem lower Pecos River, but species specific studies (e.g., Echelle and Echelle, 1978; Albeit, 1982; Humphries and Miller, 1982; Hatch et al., 1985; Kelsch and Hendricks, 1990) provided supplemental information. Additionally, studies focused on fishes of lower Pecos River tributaries (e.g., Stevenson and Buchanan, 1973; Kennedy, 1977; Cowley and Sublette, 1987; Propst, 1992) added insight for interpretation of historical and recent fish distributions.

RESULTS

Overall, the effort extended for recent collecting was similar to historical surveys of a given time period (Tables 2 and 3). Recent Carlsbad segment surveys were, in essence, a continuation of traditional NMDGF surveys (Propst, 1992; NMDGF and FWS unpublished data) with increased emphasis on native fishes such as *Cyprinodon pecosensis* (Echelle et al., 1997; Hoagstrom and Brooks, 1999) and *Cycleptus elongatus* (Propst, 1999). These efforts were similar to historical surveys, with omission of the fish barrier trap and surveys of Avalon and Red Bluff reservoirs, but with addition of boat-mounted electrofishing between Brantley Dam and Avalon Reservoir and within lower Carlsbad Lakes (Propst, 1992). Recent Toyah segment surveys were comparable to historical surveys (Table 2), but added gill-net sampling at a few locations (Hoagstrom, 1994; Larson, 1996). Recent Edwards segment surveys were least extensive compared to historical surveys (the main difference being lack of intensive sampling at two sites sensu Rhodes and Hubbs, 1992; Table 3). However, recent and historical data from the Edwards segment were considered at least marginally comparable, particularly because 1997 collections conducted by D.M. Hillis, UT-Austin, constituted a partial replication of his 1979 collections.

Forty-five native fish species have been reported from historical surveys of the lower Pecos River (not including the unsubstantiated *Phenacobius mirabilis* and *Ictiobus niger*; Table 1). Twenty-seven (60%) of these occurred in all three segments. Nine others (20%) were found in two different segments (3 in Carlsbad and Toyah, 5 in Toyah and Edwards, 1 in Carlsbad and Edwards). The remaining nine native fish species (20%) were only present in a single segment (3 in Carlsbad, 6 in Edwards). Total number of native species was 34, 35, and 39 in the Carlsbad, Toyah, and Edwards segments, respectively.

Recent collections included 30 native fish species (Table 1) with 14 historical inhabitants absent and one (*Ictalurus lupus*) uncertain, because of difficulties with identification (Yates et al., 1984; Kelsch and Hendricks, 1986). Only nine (30%) of the 30 remnant native species were found in all three segments, while seven (23%) were taken from two segments (2 in Carlsbad and Toyah, 3 in Toyah and Edwards, 2 in Carlsbad and Edwards). The remaining 14 native species (47%) were only present in collections from a single segment (5 in Carlsbad, 3 in Toyah, 6 in Edwards). The recent total of native species per segment was 18, 16, and 18 in Carlsbad, Toyah, and Edwards segments, respectively.

Table 2. Summary of fish community surveys within the lower Pecos River Toyah segment. Number of study sites and site visits is given for each survey and summarized for each of three survey periods (Post development period, 1939-1960; Near recent period, 1961-1990; Recent period, 1991-1999). Historical (1939-1990) collections were divided into two periods to provide a better comparison (i.e., even though this paper compares historical and recent collections, post-development and near recent fish communities were different, with post-development collections being more diverse. A comparison of effort from the three periods seems more informative than a comparison of collections from 51 years to those from 10). This table is believed to represent all major fish community surveys but may not represent all fish collections.

Surveys				Periods			
Survey	Method	Sites	Visits	Period	Method	Sites	Visits
UMMZ 1939-40	Bag seine	2	3 (1.5/site)	Post Development	Seine	21	50 (2.4/site)
Jameson & Lindsay 1951	Bag and minnow seine?	1	1 (1.0/site)				
Hubbs & Springer 1954	Bag and minnow seine?	6	6 (1.0/site)				
Campbell 1959	Bag and minnow seine	21	40 (1.9/site)				
Suttkus et al. 1961-1976	Minnow seine	7	9 (1.3/site)	Near Recent	Seine	11	73 (6.6/site)
Davis 1976	Minnow seine	2	2 (1.0/site)				
Hillis 1979	Minnow seine?	3	3 (1.0/site)				
Rhodes et al. 1987-88	Minnow seine	3	50 (16.7/site)				
Linam and Kleinsasser 1987	Bag and minnow seine	9	9 (1.0/site)	Recent	Seine	9	62 (6.9/site)
Hoagstrom 1993-94	Minnow seine	6	50 (8.3/site)				
Larson 1994	Minnow seine	4	4 (1.0/site)				
Hoagstrom 1998	Minnow seine	8	8 (1.0/site)				
Hoagstrom 1993-94	Gill Net	5	6 (1.2/site)		Gill Net	9	10 (1.1/site)
Larson 1994	Gill Net	4	4 (1.0/site)				

Table 3. Summary of fish community surveys within the lower Pecos River Edwards segment. Number of study sites and site visits is given for each survey and summarized for each of three survey periods (Post development period, 1939-1960; Near recent period, 1961-1990; Recent period, 1991-1999). Historical (1939-1990) collections were divided into two periods to provide a better comparison (i.e., even though this paper compares historical and recent collections, post-development and near recent fish communities were different, with post-development collections being more diverse. A comparison of effort from the three periods seems more informative than a comparison of collections from 51 years to those from 10). This table is believed to represent all major fish community surveys but may not represent all fish collections.

Surveys				Periods			
Survey	Method	Sites	Visits	Period	Method	Sites	Visits
Treviño-Robinson 1954	Bag and Minnow seine	1	1 (1.0/site)	Post Development	Seine	8	15 (1.9/site)
Hubbs & Springer 1954	Bag and Minnow seine	2	2 (1.0/site)				
Campbell 1959	Bag and Minnow seine	7	12 (1.7/site)				
Campbell 1959	Gill Net	3	3 (1.0/site)		Gill Net	3	3 (1.0/site)
Suttkus et al. 1963-1976	Seine	2	12 (6.0/site)	Near Recent	Seine	18	69 (3.8/site)
Hillis 1979	Minnow seine	17	17 (1.0/site)				
Garrett & Marsh 1980	Minnow seine	1	1 (1.0/site)				
Rhodes et al. 1987-88	Minnow seine	2	33 (16.5/site)				
Linam and Kleinsasser 1987	Bag and minnow seine	6	6 (1.0/site)				
Garrett 1991	Minnow seine/Electrofisher	1	1 (1.0/site)	Recent	Seine	11	11 (1.0/site)
Larson 1994	Minnow seine/Gill Net	1	1 (1.0/site)				
Hillis 1997	Seine	9	9 (1.0/site)				

Table 4. Introduced fishes and native/nonnative hybrids known from the mainstem lower Pecos River including Amistad Reservoir, which inundates the Pecos River-Rio Grande confluence. Historical and recent distribution of each species is given by segment. ? = No locality information. Names and taxonomic order of North American freshwater fishes follow Mayden et al. (1992). Other names follow Robins et al. (1991).

Species	Historical Distribution	Recent Distribution
Dorosoma petenense	CARLSBAD	Carlsbad, uncommon
Carassius auratus	TOYAH - EDWARDS	-
Ctenopharyngodon idella	CARLSBAD	Carlsbad, Carlsbad Lake
Cyprinella venusta	TOYAH - EDWARDS	Edwards, common
Cyprinus carpio	ALL	All, abundant in upper segment
Hybognathus placitus	CARLSBAD	Carlsbad, rare
Notemigonus crysoleucas	CARLSBAD	Carlsbad, rare
Notropis girardi	CARLSBAD	-
*Catostomus commersoni**	CARLSBAD	-
Ameiurus melas	ALL	Carlsbad, rare
Ameiurus natalis	TOYAH - EDWARDS	-
Esox lucius	EDWARDS	-
Oncorhynchus mykiss	CARLSBAD	-
Menidia beryllina	ALL	All, abundant in Carlsbad, common in Toyah, uncommon in Edwards
Fundulus grandis	ALL	All, common in Carlsbad & Toyah
Cyprinodon pecosensis x C. variegatus	ALL	All, abundant in Toyah, rare/localized elsewhere
Gambusia geiseri	EDWARDS	Edwards segment, uncommon
Morone chrysops	ALL	Carlsbad, rare
Morone saxatilis	CARLSBAD	-
Morone saxatilis x M. chrysops	CARLSBAD	-
Ambloplites rupestris	CARLSBAD	-
Lepomis auritus	EDWARDS	-
Lepomis humilis	?	-
Lepomis microlophus	EDWARDS	Edwards
Micropterus dolomieu	EDWARDS	-
Micropterus punctulatus	CARLSBAD	Carlsbad
Pomoxis annularis	ALL	Carlsbad
Pomoxis nigromaculatus	CARLSBAD	-
Perca flavescens	CARLSBAD	-
Stitzostedion canadense	EDWARDS	-
Stitzostedion vitreum	CARLSBAD	Carlsbad, rare
Cynoscion nebulosus	CARLSBAD	-
Micropogonias undulatus	CARLSBAD	-
Pogonias cromis	CARLSBAD	-
Sciaenops ocellatus	CARLSBAD - TOYAH	-
Paralichthys lethostigma	CARLSBAD	-

*Native to Pecos River headwaters, presumed introduced to the lower Pecos River.

Ten native species appeared to be thriving or have stable populations during recent collections (Table 1). Status of the remaining 20 is either diminished or tenuous (diminished species were sporadic in occurrence and/or restricted in distribution; tenuous species were very rare). *Macrhybopsis a. aestivalis*, *Notropis l. ludibundus*, and *Aplodinotus grunniens* were each represented by a single individual. The number of native species missing from recent collections was 16, 19, and 20 per segment (Carlsbad, Toyah, and Edwards respectively), representing fish species richness reductions of 47, 54, and 51% respectively.

Thirty-six introduced fish species were reported from historical lower Pecos River surveys (Table 4). Seven of these (19%) were known from all segments

and four (11%) were found in two segments (1 in Carlsbad and Toyah, 2 in Toyah and Edwards). Twenty-four introduced species (69%) were restricted to a single segment (18 to Carlsbad, 6 to Edwards). Total introduced species per segment was 26, 11, and 16 (Carlsbad, Toyah, and Edwards, respectively). Historical distribution of *Lepomis humilis* was not reported (Campbell, 1959).

Sixteen introduced fish species were present in recent collections (Table 4). Four (25%) were found in all segments, but the remaining 12 (75%) were restricted to a single segment (9 to Carlsbad, 3 to Edwards). Five of these (*Hybognathus placitus*, *Notemigonus crysoleucas*, *Ameiurus melas*, *Morone chrysops*, *Stitzostedion vitreum*) were rare, likely representing bait bucket releases (first two) or strays from reservoirs or tributaries (last three). The recent total of introduced species per segment was 13, 4, and 7 (Carlsbad, Toyah, and Edwards, respectively).

DISCUSSION

Comparison of historical and recent native fish species composition indicated significant decline. Historically, the three segments had similar fish species richness and pre-dam (i.e., pre-systematic fish survey) similarity between segments was likely even greater. The lower Pecos River did not sustain a commercial fishery (as did large rivers elsewhere in North America) so the public may have been relatively unaware of what fishes were present, causing large-river fishes (e.g., *Atractosteus spatula*, *Lepisosteus oculatus*, *Anguilla rostrata*, *C. elongatus*, and *A. grunniens*) to be poorly documented in historical accounts. For example, Hubbs (1957) believed *Lepisosteus platostomus*, collected by Pope in 1854 (see Evermann and Kendall, 1894) represented *A. spatula*, whereas Sublette et al. (1990) suggested the species captured was *L. oculatus*. Following the first development period (after 1930), *L. oculatus* occurred further upstream than *A. spatula* (Campbell, 1959; J. F. Scudday, Sul Ross State University, pers. comm.), suggesting Pope's specimen was more likely *L. oculatus*, but human-caused changes in flow regime, channel sediment, and water quality made the middle Twentieth Century lower Pecos River much different from that of 1854 (see above). Thus, it is possible both gar species were present in New Mexico prior to impoundment, neither being documented.

Researchers active throughout the second development period noted the decline of lower Pecos River fishes. During a 1947 visit to Malaga Bend, Koster complained, "Collecting to date has been disappointing. Fish are scarce. Many species which are known from both above and below are seemingly absent from this lower stretch of the Pecos" (from field notes 1939-1955). The dramatic decline of *Notropis* species serves as an example. *Notropis jemezanus*, once widespread (Campbell, 1959; Treviño-Robinson, 1955; Sublette et al., 1990), was absent from recent collections (possibly persisting in Independence Creek [Garrett, 1997; Karges, The Nature Conservancy, pers. comm.]). *Notropis l. ludibundus* disappeared from the Carlsbad segment before 1975 (Sublette, 1975) and is known from a single recent Toyah segment specimen (Hoagstrom, 1994). *Notropis amabilis* and *N. braytoni*, historically found as far upstream as Roswell, New Mexico (Hatch, 1985; Platania, 1996), are rare in recent Toyah and Edwards segment collections. *Notropis girardi*, introduced to the Carlsbad segment around 1978 (Bestgen et al., 1989), was apparently never established.

Notropis simus pecosensis now is restricted to the middle Pecos River between Sumner and Brantley dams (Sublette et al., 1990; Propst, 1999), but the nominal collection of this subspecies was made in 1854 by Pope (Chernoff et al., 1982) who surveyed the Pecos River from Black River confluence, downstream to Emigrant Crossing near Barstow, Texas (Pope, 1854). Although the exact location of Pope's *N. s. pecosensis* collection was unspecified (Evermann and Kendall, 1894; Platania, 1995), this record indicates that *N. s. pecosensis* historically inhabited the lower Pecos River when it was deep and swift, with a sand bed. By the time subsequent fish surveys were conducted, the lower Pecos River had become salty, sluggish, and silty.

Notropis orca and *N. buchanani* were rare in historical lower Pecos River collections, but common in the adjacent Rio Grande (Treviño-Robinson, 1955, 1959; Chernoff et al., 1982). Their abundance in the pre-impoundment lower Pecos River is unknown, but their disappearance from the drainage may have foreshadowed their decline in the Rio Grande. *Notropis orca* is now extinct (Chernoff et al., 1982; Bestgen and Platania, 1990; Hubbs et al., 1991), and *N. buchanani* is rare within the Rio Grande (Platania, 1990; Edwards and Contreras-Balderas, 1991). Thus, the more recent decline of *N. braytoni* and *N. jemezanus* from the lower Pecos River may justify increased concern for Rio Grande populations of these species.

Similar to developments for irrigated agriculture (Taylor, 1902; President's Water Resources Policy Commission, 1950; Lingle and Linford, 1961), attempts to establish productive sport fisheries in the lower Pecos River did not meet expectations (Campbell, 1959; Navarre, 1959, 1960; Little, 1961b, 1963a, 1963b, 1964c, 1964d, 1965). Because game-fish management efforts were largely initiated subsequent to major water development, conditions that prevented fishery success were not solely attributable to geological or human-induced factors, but represented a combination of both (Campbell, 1959; Little, 1964c; Davis, 1987). Poor and unstable water quality (Little, 1964d; Larson, 1996; Linam and Kleinsasser, 1996) and toxic algal blooms (Rhodes and Hubbs, 1992) significantly impacted game fish success. As a result of dramatic human-caused changes, the historical status of native game fishes and potential of the pre-impoundment lower Pecos River to support nonnatives will never be known.

Some native species present in historical collections may not have been established within the pre-impoundment lower Pecos River. For example, *Rhinichthys cataractae*, was common in the upper Pecos River, but infrequent in the lower Pecos River (Miller, 1977; Sublette et al., 1990). This species may have colonized tailwaters of McMillan and Avalon reservoirs during floods or with human aid. Both tailwater reaches were eventually dewatered, so absence of *R. cataractae* from recent collections is not surprising.

Etheostoma lepidum typically inhabits small streams with dense vegetation (Hubbs et al., 1953; Cowley and Sublette, 1987) and it was never abundant in the mainstem Pecos River (Hubbs and Echelle, 1972). The species may have entered the Pecos River from tributaries, colonizing spring-fed areas that dominated the mainstem after the first development period. These darters probably declined during the second development period as spring flows were depleted. Similarly, Balconian fishes (*Campostoma anomalum, Cyprinella proserpina, Dionda episcopa, N. amabilis, N. l. ludibundus, Pimephales vigilax, Scartomyzon congestus, Etheostoma grahami*) and Tamaulipan fishes (*N. braytoni, Cichlasoma cyanoguttatum*) were most abundant in spring-fed tributaries (Rhodes and Hubbs, 1992) and their decline from the lower Pecos River coincided with spring flow depletion (Linam and Kleinsasser, 1996).

Cyprinodon pecosensis and *Fundulus zebrinus* were probably uncommon in the pre-impoundment Pecos River mainstem, most likely occupying saline tributaries and floodplain wetlands (Hoagstrom and Brooks, 1999). Both species proliferated in the lower Pecos River as it was dewatered (Campbell, 1959), but loss of floodplain wetlands eventually restricted them to the mainstem and a few persistent tributaries (Hoagstrom and Brooks, 1999). Subsequently, mainstem populations were decimated by introduced congeners. A *C. pecosensis* x *C. variegatus* hybrid swarm replaced *C. pecosensis* (Echelle et al., 1987; Echelle and Connor, 1989; Wilde and Echelle, 1992), and *F. zebrinus* was replaced by *F. grandis* (Hoagstrom, 1994). *Cyprinodon pecosensis* (3 locations) and *F. zebrinus* (3 locations) persist in off-channel locations, with the largest populations of both species inhabiting upper Salt Creek, Culberson and Reeves counties, Texas (N.L. Allan, FWS; A.A. Echelle, Oklahoma State University; G.P. Garrett, TPW; J.P. Karges, The Nature Conservancy, pers. comm.).

In each lower Pecos River segment, recent native fish species richness was roughly half of historical richness. Resultant fish communities represented a response to the water quality, physical habitat, and flow regime of each segment. Differences among segments were exacerbated by toxic algal blooms and physical barriers. Native species persistent in the Carlsbad segment included lentic freshwater fauna (e.g., *Dorosoma cepedianum, Lepisosteus osseus*, centrarchids), generalist freshwater fauna (e.g., *Cyprinella lutrensis, Pimephales promelas, Menidia*

beryllina, Gambusia affinis), and riverine catostomids (e.g., *Carpiodes carpio elongatus, C. elongatus, Ictiobus bubalus*). The Carlsbad segment was heavily impacted by impoundment, agriculture, and urbanization, with significant impacts from diversion, oil field pollution, groundwater pumping, and upstream development (U.S. National Resources Planning Board, 1942; Thomas et al., 1963; Davis, 1987), readily accounting for recent absence of 16 native species. Relatively high recent introduced species richness (n=13) is attributable to presence of three large reservoirs, absence of toxic algal blooms (except in Red Bluff Reservoir), and persistence of spring flows in the city of Carlsbad, Black River, and Delaware River.

Euryhaline fishes (e.g., *D. cepedianum, C. pecosensis* x *C. variegatus, F. grandis, Lucania parva, G. affinis*) dominated the Toyah segment, which was not surprising in light of numerous impacts that concentrated salts therein, including upstream development (e.g., Carlsbad segment), local groundwater withdrawal, oil field pollution, mainstem and tributary diversion, and agriculture (Taylor, 1902; U.S. National Resources Planning Board, 1942; Grozier et al., 1966; Mace et al., 2001). Toxic algal blooms further impacted Toyah segment fishes (Rhodes and Hubbs, 1992; Hoagstrom, 1994). Failure of introduced game fishes (none taken in recent surveys) is attributable to absence of large reservoirs, absence of significant spring inflows, and toxic algal blooms. Severity of direct and indirect impacts on the Toyah segment and absence of redeeming habitat features (e.g., persistent springs) clearly account for recent absence of 19 native species.

The Edwards segment supported freshwater generalists (e.g., *C. lutrensis, C. venusta, P. vigilax, G. affinis*) and spring-dwelling specialists (e.g., *C. proserpina, D. episcopa, E. grahami*). It is possible that the Edwards segment retains species not taken in recent surveys, because recent surveys were not extensive (Table 3) and did not include gill-net or boat-mounted electrofishing collections, increasing the likelihood that riverine species (e.g., *L. oculatus, C. elongatus, I. bubalus, I. furcatus, A. grunniens*) could have escaped detection. Even so, severe upstream impacts (e.g., Carlsbad and Toyah segments) could account for the recent absence of 20 native species, especially in combination with toxic algal blooms that reduce short-term species richness and possibly cause long-term reductions (Rhodes and Hubbs, 1992). Downstream impoundment of the Edwards segment by Amistad Reservoir could also have facilitated species loss (Winston et al., 1991; Wilde and Ostrand, 1999; Lienesch et al., 2000). Persistence of nonnative game fishes in the Edwards segment may be attributed to persistent spring flows and Amistad Reservoir.

Minckley (1965) suggested that the lower Pecos River was incidentally stocked with *M. beryllina* along with estuarine sport-fishes (e.g., *Sciaenops ocellatus*). Subsequently, *M. beryllina* dispersed beyond the lower Pecos River (Hubbs and Echelle, 1972), currently ranging as far as 188 km upstream of Brantley Dam (New Mexico Fishery Resources Office, FWS, unpublished data). Incidental stockings of this sort probably introduced estuarine invertebrates (Davis, 1987) and could have played a role in establishing *C. variegatus* (*C. variegatus* were reported by Campbell in 1959 in the same time period and vicinity of *S. ocellatus* introductions, but no voucher specimens are available).

Successful introduction of *Cyprinodon variegatus* to the lower Pecos River most likely occurred after 1980, with establishment and spread facilitated by bait-bucket release (Echelle et al., 1987; Echelle and Connor, 1989; Hubbs et al., 1991; Wilde and Echelle, 1992; Echelle et al., 1997; Echelle et al., this volume). Genetic evidence suggests the species first colonized Red Bluff Reservoir via introduction from Lake Balmorhea, Reeves County, Texas (Childs et al., 1996). The Lake Balmorhea *C. variegatus* population was established from an unknown source prior to 1968 (Stevenson and Buchanan, 1973) and persists today (Echelle et al., this volume). It also served as the source for a recent *C. variegatus* introduction to Diamond Y Spring (Echelle and Echelle, 1997). The point of introduction for *F. grandis* has not been specifically investigated, but establishment in the Edwards segment (Hillis et al., 1980; Hubbs, 1982; Rhodes and Hubbs, 1992; Linam and Kleinsasser, 1996) and Carlsbad segment (Propst, 1992), prior to expansion into Toyah segment (Hoagstrom, 1994; Larson, 1996) suggests at least two separate introductions.

CONCLUSIONS

The historical fish fauna of the lower Pecos River included many riverine forms and was not fragmented by physical barriers. Early Anglo-American development (1885 to 1929) resulted in capture and diversion of surface waters and alluvial sediments, after which river substrate changed and local groundwater springs became the primary source of river flow. A second phase of Anglo-American development (1930 to 1970) reduced inflow from groundwater, in many cases directing groundwater flow away from the river, while additional dams furthered river fragmentation. As a result, lower Pecos River hydrology, geomorphology, and water chemistry were dramatically altered from a natural condition that was never quantitatively described.

In response to human induced changes, each river segment developed a distinctive fish community composed of tolerant native and introduced fishes. Native riverine fishes declined from all segments because mainstream habitats were universally impacted. Spring and wetland fishes retreated to areas sustaining substantial spring inflows (e.g., Black River, Salt Creek, Independence Creek, lower Pecos River Edwards segment). The Toyah segment, was most dramatically impacted by development. As a result, this segment suffered the greatest percent native species richness reduction and did not sustain introduced game fishes.

Intentional game fish stockings met with only short-term success while incidental stocking and bait-bucket release established nonnative euryhaline fishes. Success of game species was likely limited by unfavorable water quality, degraded habitat, and toxic algal blooms. These same factors apparently favored unintentionally introduced euryhaline fishes. Additional nonnative fish introductions and spread of locally established nonnatives continue to threaten native lower Pecos River fishes.

Because of numerous, large-scale impacts that have altered the mainstem lower Pecos River, challenges for native fish conservation are many and great. Proponents of aquatic habitat restoration and native fish protection will benefit from an appreciation of former fish community diversity and severity of impacts that changed the lower Pecos River. While it is appropriate to consider the entire lower Pecos River as a significant component of the historical range of many native Rio Grande basin fishes, it may be optimistic to expect restoration of all or even a few missing species (in light of prevailing conditions). However, a number of persistent native species (including unique Pecos River and Rio Grande forms, Table 1) would benefit from immediate population assessment and conservation activity. Improvement of conditions to preserve these species may also facilitate voluntary re-establishment of fishes occupying the adjacent Rio Grande, Pecos River tributaries, or the middle Pecos River. At least, recognition of rapid and ongoing decimation of native lower Pecos River fishes should increase awareness of the general imperilment of Rio Grande basin fishes, focusing attention on and elevating prioritization of waters where remnant native fish assemblages persist.

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LITERATURE CITED

Albeit, P. S. 1982. The ecology of the Pecos pupfish, *Cyprinodon pecosensis* Echelle and Echelle, in the lower Pecos River drainage of New Mexico (Cyprinodontiformes; Cyprinodontidae). Unpublished Master's Thesis, Eastern New Mexico University, Portales. 67 pp.

Anaya, R. 2001. An overview of the Edwards-Trinity aquifer system, central-west Texas. Pp. 100-119, *in* Aquifers of West Texas (R.E. Mace, W.F. Mullican III, and E.S. Angle, eds), Texas Water Development Board Report 356, Austin. 272 pp.

Ashworth, J. B. 1990. Evaluation of ground-water resources in parts of Loving, Pecos, Reeves, Ward, and Winkler counties, Texas. Texas Water Development Board Report 317, Austin. 51 pp.

Bachman, G. O. 1980. Regional geology and Cenozoic history of Pecos region, southeastern New Mexico. U.S. Geological Survey Open-File Report 80-1099, 116 pp.

Bestgen, K. R. and S. P. Platania. 1990. Extirpation of *Notropis simus simus* (Cope) and *Notropis orca* Woolman (Pisces: Cyprinidae) from the Rio Grande in New Mexico, with notes on their life history. Occasional Papers, Museum of Southwestern Biology, 6:1-8.

Bestgen, K. R., S. P. Platania, J. E. Brooks, and D. L. Propst. 1989. Dispersal and life history traits of *Notropis girardi* (Cypriniformes: Cyprinidae), introduced into the Pecos River, New Mexico. American Midland Naturalist, 122:228-235.

Blair, F. W. 1950. The biotic provinces of Texas. Texas Journal of Science, 2:93-117.

Brune, G. 1981. Springs of Texas, Volume 1. Branch-Smith, Inc., Fort Worth, Texas. 499 pp.

Burr, B. M. and R. L. Mayden. 1999. A new species of *Cycleptus* (Cypriniformes: Catostomidae) from Gulf Slope drainages of Alabama, Mississippi, and Lousiana, with a review of the distribution, biology, and conservation status of the genus. Alabama Museum of Natural History, Bulletin, 20:19-57.

Buth, D. G. and R. L. Mayden. 2001. Allozymic and isozymic evidence for polytypy in the North American Catostomid genus *Cycleptus*. Copeia, 2001:899-906.

Campbell, L. 1959. Basic survey and inventory of species present in the Pecos River of Texas. Dingell-Johnson Project F-5-R-5, Job B-13, Texas Game and Fish Commission, Austin. 31 pp.

Chernoff, B., R. R. Miller, and C. R. Gilbert. 1982. *Notropis orca* and *Notropis simus*, cyprinid fishes from the American Southwest, with description of a new subspecies. Occasional Papers of the Museum of Zoology No. 698, University of Michigan, Ann Arbor. 49 pp.

Childs, M. R., A. A. Echelle, and T. E. Dowling. 1996. Development of the hybrid swarm between Pecos pupfish (Cyprinodontidae: *Cyprinodon pecosensis*) and sheepshead minnow (*Cyprinodon variegatus*): a perspective from allozymes and MTDNA. Evolution. 50:2014-2022.

Coburn, M. M. 1982. Anatomy and relationships of *Notropis atherinoides*. Unpublished Ph.D. dissertation, Ohio State University, Columbus. 384 pp.

Cowley, D. E. and J. E. Sublette. 1987. Distribution of fishes in the Black River drainage, Eddy County, New Mexico. The Southwestern Naturalist, 32:213-221.

Davis, J. R. 1980. Species composition and diversity of benthic macroinvertebrate populations of the Pecos River, Texas. The Southwestern Naturalist, 25:241-256.

Davis, J. R. 1981. Diet of the Pecos River Pupfish, *Cyprinodon pecosensis* (Cyprinodontidae). The Southwestern Naturalist, 24:535-540.

Davis, J. R. 1987. Faunal characteristics of a saline stream in the northern Chihuahuan Desert. Contributed papers of the second symposium on resources of the Chihuahuan Desert region, United States and Mexico. Chihuahuan Desert Research Institute, Alpine, Texas, 18 pp.

Dearen, P. 1996. Crossing Rio Pecos. Texas Christian University Press, Fort Worth, 196 pp.

Echelle, A. A. and P. J. Connor. 1989. Rapid, geographically extensive genetic introgression after secondary contact between two pupfish species (*Cyprinodon*, Cyprinodontidae). Evolution, 43:717-727.

Echelle, A. A. and A. F. Echelle. 1978. The Pecos River pupfish, *Cyprinodon pecosensis* n. sp. (Cyprinodontidae), with comments on its evolutionary origin. Copeia, 1978:569-582.

Echelle, A. A. and A. F. Echelle. 1997. Genetic introgression of endemic taxa by non-natives: a case study with Leon Springs pupfish and sheepshead minnow. Conservation Biology, 11:153-161.

Echelle, A. A., A. F. Echelle, and D. R. Edds. 1987. Population structure of four pupfish species (Cyprinodontidae: *Cyprinodon*) from the Chihuahuan Desert region of New Mexico and Texas: allozymic variation. Copeia, 1987:668-681.

Echelle, A. A., C. W. Hoagstrom, A. F. Echelle, and J. E. Brooks. 1997. Expanded occurrence of genetically introgressed pupfish (Cyprinodontidae: *Cyprinodon pecosensis* x *variegatus*) in New Mexico. The Southwestern Naturalist, 42:336-339.

Edwards, R. J. and S. Contreras-B. 1991. Historical changes in the ichthyofauna of the Lower Rio Grande (Rio Bravo del Norte), Texas and Mexico. The Southwestern Naturalist, 36:201-212.

Edwards, R. J., G. Longley, R. Moss, J. Ward, R. Matthews, and B. Stewart. 1989. A classification of Texas aquatic communities with special consideration toward the conservation of endangered and threatened taxa. Texas Journal of Science, 41:231-240.

Eisenhour, D. J. 1997. Systematics, variation, and speciation of the *Macrhybopsis aestivalis* complex (Cypriniformes: Cyprinidae) west of the Mississippi River. Unpublished Ph.D. dissertation, Southern Illinois University, Carbondale, 260 pp.

Evermann, B. W. and W. C. Kendall. 1894. The fishes of Texas and the Rio Grande Basin, considered chiefly with reference to their geographic distribution. U.S. Fish Commission, Bulletin, 12:57-126 with plates.

Freeman, W. B. and R. H. Bolster. 1911. Surface water supply of the United States, 1909, Part VIII. Western Gulf of Mexico. U.S. Geological Survey Water-Supply Paper 268, 107 pp.

Garrett, G. P. 1997. Chihuahuan Desert fishes status survey. Final Report, Grant Number E-1-8, Endangered and Threatened Species Conservation, Project E410. Texas Parks and Wildlife Department, Ingram, 17 pp.

Garrett, G. P. and R. J. Edwards. 2001. Regional ecology and environmental issues in West Texas. Pp. 56-65, *in* Aquifers of West Texas (R.E. Mace, W.F. Mullican III, and E.S. Angle, eds), Texas Water Development Board Report 356, Austin, Texas, 272 pp.

Grover, N. C., G. A. Gray, and C. E. Ellsworth. 1922. Surface water supply of the United States, 1918, Part VIII. Western Gulf of Mexico basins. U.S. Geological Survey Water-Supply Paper 478, 106 pp.

Grozier, R. U., H. W. Albert, J. F. Blakely, and C. H. Hembree. 1966. Water-delivery and low-flow studies, Pecos River, Texas, quantity and quality, 1964 and 1965. Texas Water Development Board Report 22, Austin, Texas, 21 pp.

Hatch, M. D. 1985. The native fish fauna of major drainages east of the Continental Divide in New Mexico. Unpublished Master's Thesis, Eastern New Mexico University, Portales, 33 pp, plus appendix.

Hatch, M. D., W. H. Baltosser, and C. G. Schmitt. 1985. Life history and ecology of the bluntnose shiner (*Notropis simus pecosensis*) in the Pecos River of New Mexico. The Southwestern Naturalist, 30:555-562.

Havenor, K. C. 1968. Structure, stratigraphy, and hydrogeology of the northern Roswell Artesian Basin, Chaves County, New Mexico. State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM, Circular 93, 30 pp.

Hill, C. A. 1996. Geology of the Delaware Basin, Guadalupe, Apache, and Glass mountains, New Mexico and west Texas. Society for Sedimentary Geology, Permian Basin Section-SEPM, Publication No. 96-39, 480 pp.

Hillis, D. M. Unpublished. The heterothermic vertebrates of the lower Pecos River drainage, Pecos, Crockett, Terrell, and Val Verde counties, Texas. Unpublished Manuscript, 50 pp, plus attachments.

Hillis, D. M., E. Milstead, and S. L. Campbell. 1980. Inland records of *Fundulus grandis* (Cyprinodontidae) in Texas. The Southwestern Naturalist, 25:271-272.

Hiss, W. L. 1980. Movement of ground water in Permian Guadalupian aquifer systems, southeastern New Mexico and western Texas. New Mexico Geological Society Guidebook, 31st Field Conference, Trans-Pecos Region:85-90.

Hoagstrom, C. W. 1994. Relative abundance and niche partitioning in the fish community of the Pecos River, Pecos County, TX. Unpublished Master's Thesis, Sul Ross State University, Alpine, Texas. 136 pp.

Hoagstrom, C. W. and J. E. Brooks. 1999. Distribution, status, and conservation of the Pecos pupfish, *Cyprinodon pecosensis*. Technical Report No. 2. New Mexico Department of Game and Fish, Santa Fe, 76 pp.

Hood, J. W. 1963. Saline ground water in the Roswell Basin, Chaves and Eddy counties New Mexico, 1958-1959. U.S. Geological Survey Water-Supply Paper 1539-M, 46 pp.

Howard, C. S. 1942. Quality of stored water available for use in the lower basin of the Pecos River, Texas. American Geophysical Union, Transactions, 23:593-598.

Hubbs, C. L. and J. D. Black. 1940. Status of the Catostomid fish, *Carpiodes carpio elongatus* (Meek). Copeia, 1940:226-230.

Hubbs, C. L. and R. R. Miller. 1965. Studies of Cyprinodont fishes. XXII. Variation in *Lucania parva*, its establishment in western United States, and description of a new species from an interior basin in Coahuila, México. Museum of Zoology, University of Michigan, Miscellaneous Publications, No. 127, 110 pp.

Hubbs, C. 1954. Corrected distributional records for Texas fresh-water fishes. Texas Journal of Science, 6:277-291.

Hubbs, C. 1957. Distributional patterns of Texas fresh-water fishes. The Southwestern Naturalist, 2:89-104.

Hubbs, C. 1982. Occurrence of exotic fishes in Texas waters. Pearce-Sellards Series, No. 36, 18 pp.

Hubbs, C. 1990. Declining fishes of the Chihuahuan Desert. Pp. 89-96 *in* Third Symposium on Resources of the Chihuahuan Desert Region, U.S. and Mexico (A.M. Powell, R.R. Hollander, J.C. Barlow, W.B. McGilivray, and D.J. Schmidly, eds). Chihuahuan Desert Research Institute, Alpine, Texas.

Hubbs, C. and A. A. Echelle. 1972. Endangered non-game fishes of the upper Rio Grande Basin. Pp. 147-167 *in* Symposium on rare and endangered wildlife of the southwestern United States. New Mexico Department of Game and Fish, Santa Fe, New Mexico.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science, Supplement, Vol. 43(4), 56 pp.

Hubbs, C., R. A. Kuehne, and J. C. Ball. 1953. The fishes of the upper Guadalupe River, Texas. Texas Journal of Science, 5:216-251.

Humphries, J. M. and R. R. Miller. 1982. Taxonomic status, ecology, and distribution of the headwater catfish, *Ictalurus lupus*. Final Report, Contract No. 14-16-0002-81-210. Museum of Zoology, University of Michigan, Ann Arbor, Michigan, 45 pp.

Hufstetler, M. and L. Johnson. 1993. Watering the land, the turbulent history of the Carlsbad Irrigation District. National Park Service, Rocky Mountain Region, Denver, 180 pp.

James, T. L. and A. De La Cruz. 1989. *Pyrmnesium parvum* Carter (Chrysophyseae) as a suspect of mass mortalities of fish and shellfish communities in western Texas. Texas Journal of Science, 41:429-430.

Jones, I. C. 2001. Cenozoic Pecos alluvium aquifer. Pp. 120-134, *in* Aquifers of West Texas (R.E. Mace, W.F. Mullican III, and E.S. Angle, eds), Texas Water Development Board Report 356, Austin, Texas, 272 pp.

Kelley, V. C. 1971. Geology of the Pecos country, southeastern New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 24, 78 pp., with plates.

Kelsch, S. W. and F. S. Hendricks. 1986. An electrophoretic and multivariate morphometric comparison of the American catfishes *Ictalurus lupus* and *I. punctatus*. Copeia, 1986:646-652.

Kelsch, S. W. and F. S. Hendricks. 1990. Distribution of the headwater catfish *Ictalurus lupus* (Osteichthyes: Ictaluridae). The Southwestern Naturalist, 35:292-297.

Kennedy, S. E. 1977. Life history of the Leon Springs pupfish, *Cyprinodon bovinus*. Copeia, 1977:93-103.

King, P. B. 1935. Outline of structural development of Trans-Pecos Texas. American Association of Petroleum Geologists, Bulletin, 19:221-261.

Koster, W. J. 1939-1955. Field Notes. Museum of Southwestern Biology, University of New Mexico, Albuquerque.
Koster, W. J. 1957. Guide to the fishes of New Mexico. University of New Mexico Press, Albuquerque, 116 pp.

LaFave, J. I. 1987. Groundwater flow delineation in the Toyah Basin of Trans-Pecos Texas. Unpublished Master's Thesis, University of Texas, Austin, 159 pp.

Larson, G. L. 1996. Fish community structure in relation to water quality and habitat in the upper Pecos River, Texas. Texas Natural Resource Conservation Commission, Austin, Texas, 28 pp.

Lee, W. T. 1925. Erosion by solution and fill. U.S. Geological Survey Bulletin, 760: 107-121.

Leftwich, W. J. 1987. Tracks along the Pecos. Elliot Printing Co., Pecos, Texas, 74 pp.

Lienesch, P. W., W. I. Lutterschmidt, and J. F. Schaefer. 2000. Seasonal and long-term changes in the fish assemblage of a small stream isolated by a reservoir. The Southwestern Naturalist, 45:274-288.

Linam, G. W. and L. J. Kleinsasser. 1996. Relationship between fishes and water quality in the Pecos River, Texas. River Studies Report No. 9, Resource Protection Division, Texas Parks and Wildlife Department, Austin, Texas, 10 pp.

Lingle, R. T. and D. Linford. 1961. The Pecos River Commission of New Mexico and Texas. A report of a decade of progress: 1950-1960. The Rydal Press, Santa Fe, New Mexico, 284 pp.

Little, R. G. 1960a. Periodic check of Carlsbad Municipal Lake. Job Completion Report, Federal Aid Project F-22-R-1, Work Plan 4, Job No. I-1, 4 pp.

Little, R. G. 1960b. Periodic check of Red Bluff Reservoir. Job Completion Report, Federal Aid Project F-22-R-1, Work Plan 4, Job No. I-1, 6 pp.

Little, R. G. 1961a. Periodic check of Avalon Reservoir. Job Completion Report, Federal Aid Project F-22-R-2, Work Plan 4, Job No. I-1, 3 pp.

Little, R. G. 1961b. Periodic check of fish populations between McMillan and Avalon reservoirs. Job Completion Report, Federal Aid Project F-22-R-2, Work Plan 4, Job No. I-1, 5 pp.

Little, R. G. 1963a. Periodic check of fish populations between McMillan and Avalon reservoirs. Job Completion Report, Federal Aid Project F-22-R-4, Work Plan 4, Job No. I-1, 4 pp.

Little, R. G. 1963b. Routine periodic check of Pecos River fish barrier and trap no. 1. Job Completion Report, Federal Aid Project F-22-R-4, Work Plan 4, Job No. I-1, 4 pp.

Little, R. G. 1964a. Avalon Canal fish salvage. Job Completion Report, Federal Aid Project F-22-R-5, Work Plan 4, Job No. I-1, 2 pp.

Little, R. G. 1964b. Periodic check of Avalon Reservoir. Job Completion Report, Federal Aid Project F-22-R-5, Work Plan 4, Job No. I-1, 3 pp.

Little, R. G. 1964c. Periodic check of Carlsbad Municipal Lake. Job Completion Report, Federal Aid Project F-22-R-5, Work Plan 4, Job No. I-1, 3 pp.

Little, R. G. 1964d. Resurvey of the Pecos River from the Texas-New Mexico line north to Tansill Dam in Carlsbad, New Mexico. Job Completion Report, Federal Aid Project F-22-R-4, Work Plan 4, Job B-1-A(1), 27 pp.

Little, R. G. 1965. Resurvey of the Pecos River from the Texas-New Mexico line north to Tansill Dam in Carlsbad, New Mexico. Job Completion Report, Federal Aid Project F-22-R-6, Work Plan 4, Job B-1-A(3), 6 pp.

Mace, R. E., W. F. Mullican III, and E. S. Angle (editors). 2001. Aquifers of West Texas. Texas Water Development Board Report 356. Texas Water Development Board, Austin, Texas, 272 pp.

Maley, V. C. and R. M. Huffington. 1963. Cenozoic fill and evaporate solution in the Delaware Basin, Texas and New Mexico. Geological Society of America, Bulletin, 64:539-545.

Mayden, R. L., B. M. Burr, L. M. Page, and R. R. Miller. 1992. The native freshwater fishes of North America. Pp. 827-863 *in*: R.L. Mayden (editor). Systematics, historical ecology, & North American freshwater fishes. Stanford University Press, Stanford, California.

Mayden, R. L. and C. R. Gilbert. 1989. *Notropis ludibundus* (Girard) and *Notropis tristis* (Girard), replacement names for *N. stramineus* (Cope) and *N. topeka* (Gilbert) (Teleostei:Cypriniformes). Copeia, 1989:1084-1089.

Meinzer, O. E., B. C. Renick, and K. Bryan. 1926. Geology of No. 3 reservoir site of the Carlsbad irrigation project, New Mexico, with respect to water-tightness. U.S. Geological Survey Water-Supply Paper 580-A, 39 pp.

Miller, R. R. 1977. Composition and derivation of the native fish fauna of the Chihuahuan Desert region. Pp. 365-381 *in*: R.H. Wauer and D.H. Riskind (editors). Symposium on the biological resources of the Chihuahuan Desert Region, United State and Mexico. U.S. Department of the Interior, National Park Service Transactions and Proceedings Series, No. 3.

Minckley, W. L. 1965. Records of atherinid fishes at inland localities in Texas and Northern Mexico. Great Basin Naturalist, 25:73-76.

Navarre, R. J. 1959. Pecos River fish barrier and trap no. 1 1958-1959. Job Completion Report, Federal Aid Project F-10-R-4, Work Plan 4, Job No. Cl-2-2, 24 pp.

Navarre, R. J. 1960. Pecos River fish barrier and trap no. 1 1958-1959. Job Completion Report, Federal Aid Project F-10-R-4, Work Plan 4, Job No. C-1-2-3, 25 pp.

Platania, S. P. 1990. The ichthyofauna of the Rio Grande drainage, Texas and Mexico, from Boquillas to San Ygnacio. Report to U.S. Fish and Wildlife Service, Arlington, Texas, 83 pp.

Platania, S. P. 1995. Distribution, relative abundance, and conservation status of Pecos bluntnose shiner, *Notropis simus pecosensis*. Report to New Mexico Department of Game and Fish, Santa Fe, 32 pp.

Platania, S.P. 1996. Preliminary systematic and taxonomic analysis of Rio Grande shiner, *Notropis jemezanus*, and the *Notropis* (*Notropis*) complex in the Rio Grande basin. Division of Fishes, Museum of Southwestern Biology, Department of Biology, University of New Mexico, Albuquerque, New Mexico, 47 pp.

Pope, J. 1854. Report of exploration of a route for the Pacific Railroad, near the thirty-second parallel of north latitude, from the Red River to the Rio Grande. Explorations and Surveys for a Railroad from the Mississippi River to the Pacific Ocean. War Department. Washington, 50 pp. plus appendices.

President's Water Resources Policy Commission. 1950. Ten rivers in America's future, No. 4. The Rio Grande. Volume 2, The Report of the President's Water Resources Policy Commission, U.S. Government Printing Office, Washington, 67 pp.

Propst, D. L. 1992. Inventory and monitoring of warmwater stream fish communities in New Mexico. Project Completion Report 1 July 1989 – 30 June 1992, Federal Aid in Fisheries Project FW-17-RD, 143 pp.

Propst, D. L. 1999. Threatened and endangered fishes of New Mexico. Technical Report No. 1. New Mexico Department of Game and Fish, Santa Fe, 84 pp.

Rauchenberger, M. 1989. Systematics and biogeography of the genus *Gambusia* (Cyprinodontiformes: Poecilidae). American Museum Novitates, No. 2951, 74 pp.

Rhodes, K. and C. Hubbs. 1992. Recovery of Pecos River fishes from a red tide fish kill. The Southwestern Naturalist, 37:178-187.

Richey, S. F., J. G. Wells, and K. T. Stephens. 1985. Geohydrology of the Delaware Basin and vicinity, Texas and New Mexico. U.S. Geological Survey Water-Resources Investigations Report 84-4077. Denver, Colorado, 99 pp.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. Common and scientific names of fishes from the United States and Canada. Special Publication 20, American Fisheries Society, Bethesda, Maryland, 183 pp.

Robinson, T. W. and W. B. Lang. 1938. Geology and groundwater conditions of the Pecos River Valley in the vicinity of Laguna Grande de la Sal, New Mexico with special reference to the salt content of the river water. 12th and 13th Biennial Reports of the State Engineer of New Mexico, Santa Fe: 77-100.

Schroeder, A. H. and D. S. Matson. 1965. A colony on the move, Gaspar Castaño de Sosa's Journal, 1590-1591. Alphabet Printing Co., Salt Lake City, 196 pp.

Sharp, J. M., Jr. 2001. Regional groundwater flow systems in Trans-Pecos Texas. Pp. 41-55, *in* Aquifers of West Texas (R.E. Mace, W.F. Mullican III, and E.S. Angle, eds), Texas Water Development Board Report 356, Austin, Texas, 272 pp.

Smith, M. L. and R. R. Miller. 1986. The evolution of the Rio Grande Basin as inferred from its fish fauna. Pp. 457-485 *in*: C.H. Hocutt and E.O. Wiley (editors). The zoogeograpy of North American freshwater fishes. John Wiley & Sons, New York.

Stevenson, M. M. and T. M. Buchanan. 1973. An analysis of hybridization between the cyprinodont fishes *Cyprinodon variegatus* and *C. elegans*. Copeia, 1973:682-692.

Sublette, J. E. 1975. A survey of the fishes of the Pecos, Canadian and Arkansas drainages in New Mexico. Report to New Mexico Department of Game and Fish, Santa Fe, 15 pp. plus appendices.

Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque, 393 pp.

Tanyolac, J. 1973. Morphometric variation and life history of the cyprinid fish *Notropis stramineus* (Cope). University of Kansas Museum of Natural History, Occasional Papers, No. 12:1-28.

Taylor, T. U. 1902. Irrigation systems of Texas. U.S. Geological Survey Water-Supply Paper 71, 129 pp.

Thomas, H. E., T. G. McLaughlin, I. J. Winograd, E. D. Gordon, C. S. Conover, and L. J. Bjorklund. 1963. Effects of drought in the Rio Grande Basin, drought in the southwest 1942-56. U.S. Geological Survey Professional Paper 372-D, 59 pp.

Thomas, R. G. 1972. The Geomorphic evolution of the Pecos River system. Baylor Geological Studies, Bulletin No. 22. Baylor University, Waco, Texas. 40 pp.

Treviño-Robinson, D. 1955. The ichthyofauna of the lower Rio Grande river, from the mouth of the Pecos to the Gulf of Mexico. Unpublished Master's Thesis, University of Texas, Austin, 107 pp.

Treviño-Robinson, D. 1959. The ichthyofauna of the Lower Rio Grande, Texas and Mexico. Copeia, 1959:253-256.

U. S. Geological Survey. 1900. Operations at river stations, 1899, a report of the division of hydrography, Part III. U.S. Geological Survey Water-Supply Paper 37, 298 pp.

U. S. National Resources Planning Board. 1942. The Pecos River joint investigation, reports of participating agencies. U.S. Government Printing Office, Washington, 407 pp.

West, S. W. and W. L. Broadhurst. 1975. Summary appraisals of the nation's ground-water resources-Rio Grande region. U.S. Geological Survey Professional Paper 813-D, 39 pp.

Wiebe, A. H., J. G. Burr, and H. E. Faubion. 1934. The problem of stream pollution in Texas with special reference to salt water from oil fields. Transactions of the American Fisheries Society, 64:81-86.

Wilde, G. R. and A. A. Echelle. 1992. Genetic status of Pecos pupfish populations after establishment of a hybrid swarm involving and introduced congener. Transactions of the American Fisheries Society, 121:277-286.

Wilde, G. R. and K. G. Ostrand. 1999. Changes in the fish assemblage of an intermittent prairie stream upstream from a Texas impoundment. Texas Journal of Science, 51:203-210.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society, 120:98-105.

Yates, T. L., M. A. Lewis, and M. D. Hatch. 1984. Biochemical systematics of three species of catfish (genus *Ictalurus*) in New Mexico. Copeia, 1984:97-101.

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